MEDICAL DECISION ANALYSIS -- AN APPLICATION IN HYPERTENSION

Robert Edwin Kapernick

NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

MEDICAL DECISION ANALYSIS --

AN APPLICATION IN HYPERTENSION

by

Robert Edwin Kapernick

March 1975

Thesis Advisor: W. C. Giauque

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Medical Decision Analysis --

An Application in Hypertension

by

Robert Edwin Kapernick
Lieutenant, United States Navy
B.S., Montana State University, 1965

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF DRAWINGS

I. INTRODUCTION

In recent years decision problems in medicine have become increasingly important because of rapidly expanding technology and higher risks in terms of money and human life. A medical problem of fundamental importance is determining proper diagnosis-treatment procedures for specific diagnostic categories. Medical training is traditionally along the lines of specific diseases, their symptoms and their treatments. However, little training is given for considering the uncertainty in the diagnosis and the effect of that uncertainty upon the treatment. Another difficulty in treating specific diagnostic categories is the complexity of the issues involved. Doctors must often choose between a number of conflicting factors and try to reach decisions with little cost and probability data to aid them.

Decision analysis is a rational, systematic approach that allows one to cope with problem uncertainties and complexities. These attributes make decision analysis an attractive method for obtaining optimal diagnosis-treatment procedures in specific diagnostic categories.

A. PURPOSES

The purposes of this thesis are three-fold. The first purpose is to demonstrate that decision analysis can be used to obtain optimal diagnosis-treatment procedures in specific diagnostic categories. The second purpose is to provide the author with experience in conducting a decision analysis. The third purpose is to generate interest in the use of decision analysis in medical decision-making.

B. HYPERTENSION

A specific diagnostic category where diagnosis treatment procedures are particularly controversial is hypertension. The lack of standardization in diagnosing and treating hypertension, and the high incidence of hypertension among the general public makes the specific category of hypertension an attractive candidate for decision analysis.

C. THESIS ORGANIZATION

This thesis is organized in the following manner. Chapter II provides decision analysis methodology necessary to solve the hypertension problem. Chapter III develops the medical background of hypertension and discusses possible test and treatment alternatives. Chapter IV formulates the hypertension problem. This formulation consists of structuring diagnosis-treatment alternatives so that problem uncertainties and complexities can be analyzed. Chapter V solves the hypertension problem and discusses solution results.

II. DECISION ANALYSES OF SPECIFIC DIAGNOSTIC CATEGORIES

Decision analysis is a rational, systematic technique well-suited for solving complex and uncertain problems. Recently, there has been an increase in applying decision analysis to medical problems. Among the reasons for this are: medical decisions have important consequences in cost, suffering, and death; medical problems are complex and involve uncertainty; and public interest in medicine is high [1]. A number of articles describe the application of decision analysis to medical problems. In particular, decision analysis has been fruitfully applied to severe abdominal pain, acute renal failure, and the sore-throat problem [2].

This paper proposes that decision analyses of specific diagnostic categories are a viable means of obtaining substantive diagnosis-treatment procedures. Based on the successful application of decision analysis to medical problems in the past, additional analyses should be undertaken to provide a richer reservoir of optimal treatment procedures.

This chapter is divided into two parts. Section A gives a brief discussion of problem characteristics that cause complexities in formal analyses and establishes which of these characteristics occur when evaluating diagnostic categories. The majority of the chapter is devoted to Section B where the methodology for decision analysis is developed. This methodology provides a foundation for a decision analysis of hypertension.

A. PROBLEM COMPLEXITIES

"Real-life" problems have varying degrees of complexity. Giauque [1] states that a problem can be:

1. well-defined or ill-defined,

2. treated as certain or uncertain, and

3. single attributed or multiattributed.

Ill-defined problems are cases where decision alternatives and the consequences of these alternatives are poorly understood. In these situations, effort is required to define critical questions, options, and relevant considerations before the problem can be meaningfully discussed. Uncertainty occurs when the exact value of the result for a decision alternative is unknown; however, for any given alternative, some results are more likely than others. Multiattributed problems have more than one important consequence that must be considered when evaluating each decision alternative. A decision-maker must either implicitly or explicitly make trade-offs among these consequences when evaluating each alternative. The complexity of a problem depends on the degree to which it is ill-defined, uncertain, and multi-attributed.

The problem of evaluating specific diagnostic categories for proper diagnosis-treatment procedures is essentially well-defined. The alternatives and the consequences that can occur as a result of these alternatives are usually known. This point can be illustrated by using the example of the standard sore-throat problem. The fundamental treatment alternatives are to either prescribe an antibiotic or do nothing. The possible consequences for either of these alternatives can be logically

divided into factors related to cost (e.g., cost of medicine to the patient or cost of lost time if the patient becomes ill) and factors related to health (e.g., patient incurring strep throat or patient experiencing a drug reaction). Although there is more than one possible alternative and although each alternative has several consequences, the physician is usually cognizant of these alternatives and consequences.

Specific diagnostic categories, however, are complicated by both a need to allow for multiple outcomes and the need to allow for uncertainty in diagnostic and treatment procedures. Returning to the sore-throat problem, uncertainty occurs because the exact result for either alternative is not known. Some patients will derive very little benefit from an antibiotic, while others are markedly improved. And in an extreme case, a patient can incur a violent drug reaction and possibly die. The problem is multiattributed in the sense that the doctor is confronted with several measures of patient welfare which must be simultaneously considered for each alternative. He must make trade-offs among factors related to health and cost when choosing a treatment procedure.

To conclude, specific diagnostic categories are reasonably well-defined but they must be treated as uncertain and multiattributed. A formal analysis technique must be able to cope with uncertainty and multiple consequences.

B. DECISION ANALYSIS METHODOLOGY

Decision analysis is a rational, systematic approach to problem solving. Briefly, decision analysis allows one to [1]:

1. outline all alternatives and to consider all possible consequences of each alternative in a systematic way,
2. break a large, complex problem down into a series of smaller, simpler problems so that different experts or organizational units can contribute to the solution of the problem in their particular areas,
3. specify and quantify uncertainty, and determine how critical the uncertain variables are,
4. specify, in a logical manner, the trade-offs one is willing to make among outcomes,
5. determine the worth of gathering further information, and finally
6. determine which decision is the best one to make, and to calculate a measure of how much better that decision is than any other alternative. This last point is useful in deciding, for example, whether factors ignored in the formal part of the analysis could possibly change the decision.

These attributes make decision analysis an attractive method for coping with the uncertainty and multiple consequences involved in studying specific diagnostic categories.

The purpose of this section is to acquaint those unfamiliar with decision analysis with its theory and techniques to the extent necessary to formulate and solve the hypertension problem. The text of this section is taken from a thesis by Kerns [3] and is included in the thesis body to serve as a convenient reference for the reader and to maintain the continuity of the chapter. A more comprehensive treatment of decision analysis is available from Raiffa [4], Giauque [5], and Keeney [6], to name a few.

Formal decision analysis is a systematic process comprising the following steps:

1. structuring the problem,
2. assessing relative preferences for possible consequences,

3. evaluating the probabilities for uncertainties, and

4. determining the best course of action from the information in the preceding steps.

This section is organized to explain the methodology of decision analysis for each step in the formal analysis. Before proceeding, it is necessary to explain certain terms and notations which are used throughout the remaining parts of this section.

1. <u>Clarification of Terms and Notations</u>

The terms "is indifferent to," "is preferred to," "lottery" and "utility function," are widely used in the following section of this thesis. For clarity, they need to be explained. The term "is indifferent to" is to be used to mean the same as the statement "the decision-maker is indifferent to receiving either of the outcomes." The term "A is preferred to B" is to be used to mean the same as the statement "the decision-maker prefers A over B."

The term "lottery" is defined as a gamble of some uncertain event E where the prize X^* is won if the event E occurs and the prize X_* is won if the event E does not occur. Let p^* represent the probability that E occurs and let $1 - p^*$ represent the probability that E does not occur. Notationally, the lottery will be represented as $< X^*, p^*, X_* >$.

The term "utility function" is defined as a function u which assigns a real value to every consequence such that u(a) is larger than u(b) if and only if consequence a is preferred to consequence b. The notation u(a) is expressed as the "utility of consequence a."

With the above terms clarified, the steps in a formal decision analysis process can be explained. The first step in this process is to structure the problem.

2. Problem Structure

In structuring a problem in which events are uncertain, the options or alternatives are enumerated. Next, all the events that can possibly occur are specified. As a last step, the alternatives and uncertain events are arranged in chronological order.

A type of diagram known as a decision-flow diagram or "tree" is a useful tool in decision analysis. It is a chronological arrangement of the alternatives which are controlled by the decision-maker and the events determined by chance. To illustrate the construction of a decision-flow diagram, consider the following problem. A decision-maker is faced with two alternatives, I and II. Both alternatives involve a situation where the outcomes a or b are uncertain. If a occurs, then the decision-maker must decide between alternatives III and IV. Alternative III also involves an uncertain situation leading to either the outcome c or d.

The decision-flow diagram is shown in Figure 1. Observe that the branching points or forks are of two types: decision forks and chance forks. A decision fork is designated by a small square and a chance fork by a small circle. There is additional information provided in the diagram which will be discussed in the sections below.

With the alternatives and uncertain events described by a decision-flow diagram, the next step in the decision analysis process is the assessment of the relative preferences for the consequences.

3. Establishment of Preferences

The establishment of preferences for the consequences provides the decision-maker with the basis for the rational choice between the alternatives. This depends upon the views and attitudes of the

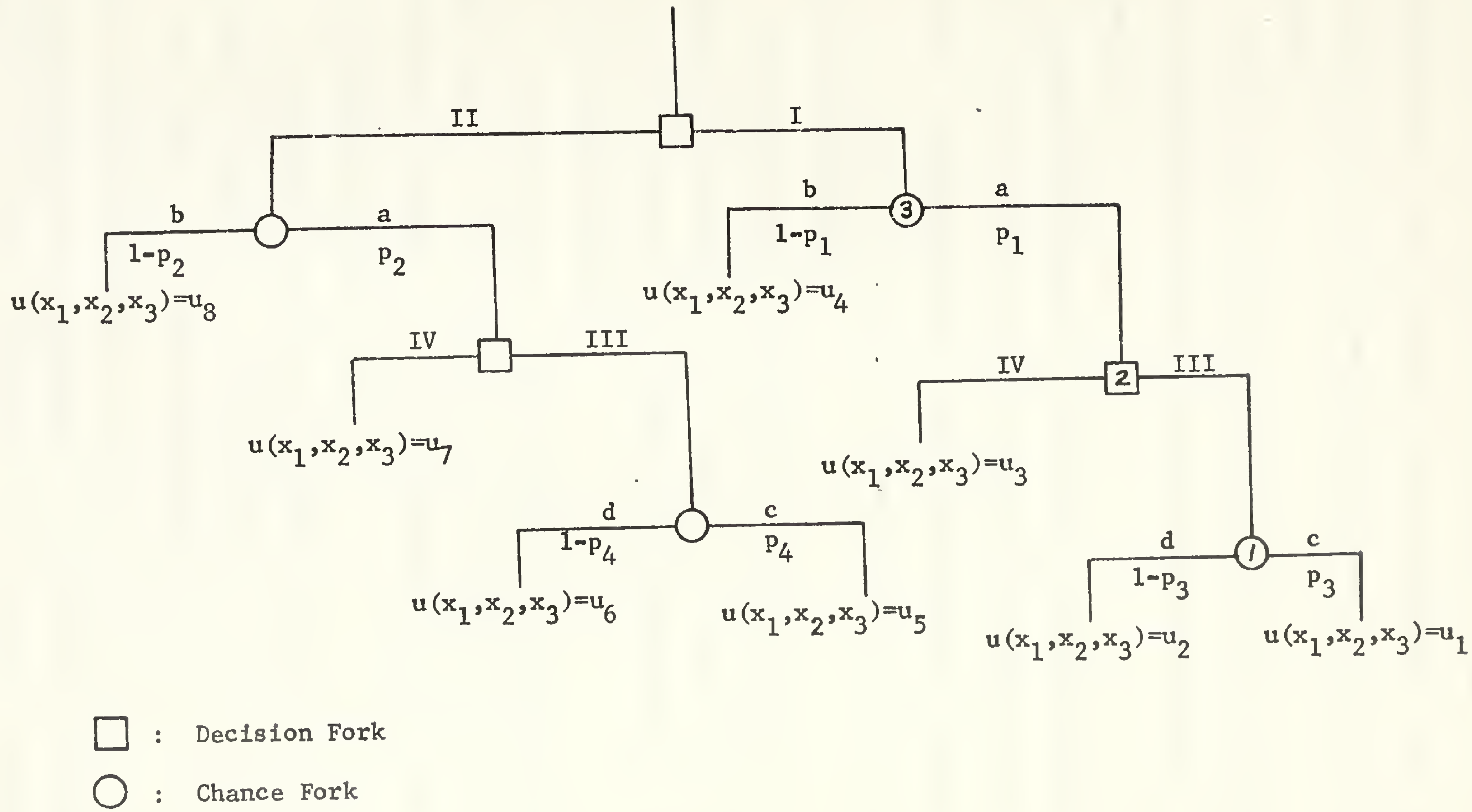


Figure 1. Example Decision-Flow Diagram

decision-maker. The consequences may encompass a number of factors or attributes such as cost, schedule and performance. These attributes might also be of an intangible nature such as goodwill, morale and politics.

In this step in the decision analysis process, an objective function is defined to indicate a measure for the preferences for the consequences.

A general methodology for defining an objective function in decision analysis problems exists in the form of utility theory. In this thesis no attempt is made to develop the theory in detail. It will be developed only to the extent necessary to formulate and solve the hypertensive problem.

Consequences may be described by a single attribute or a multiple set of attributes. Both situations are applicable to the analysis in this thesis and are separately presented below.

a. Single Attributes

In the case of a single attribute, an objective function, hereafter called a utility function, can be defined which has the property that the maximum expected utility among the alternatives indicates the most preferred action.

A utility function with a single attribute can be constructed in the following manner. Define X^* and X_* as the upper and lower limits over a range of possible consequences X_i such that $X^* \geq X_i \geq X_*$. For every possible consequence X_i, define the utility $u(X_i)$ as the value p_i such that the decision-maker is indifferent to receiving X_i for certain and receiving the lottery $< X^*, p_i, X_* >$. The value of p_i

ranges from zero to one, where by convention, $u(X^*)$ equals one and $u(X_*)$ equals zero.

Once a set of points (X_i, p_i) have been established, a utility curve may be drawn. Figure 2 illustrates three possible utility curves. A utility curve generally has two characteristics. It is smooth and the general shape of the curve is either convex, straight or concave as illustrated respectively by curves 1, 2 and 3 of Figure 2. Any break in the curve would indicate either an inconsistency in the choices for p_i in the lottery $< X^*, p_i, X_* >$ used to assess the points of the curve, or a quantum jump in preference for a small change in X_i. A convex curve indicates a risk averse behavior. That is, the decision-maker is more inclined to take a consequence known for sure than to take a gamble with the same expected value. A concave curve indicates that the decision-maker is risk seeking. He is more inclined to take the gamble than to take the known consequence. A straight line indicates that the decision-maker acts on the expected value of the consequence. He is neither risk averse nor risk seeking.

Once the utility curve is established for a single attribute consequence, a value from one to zero is assigned to each consequence corresponding to the point on the curve. A higher value for a consequence indicates greater preference for that consequence than for a consequence with a lower utility value.

b. Multiple Attributes

The basic concept of the construction of a utility function with a single attribute described above can be generalized to the case where many attributes must be considered. However, the above

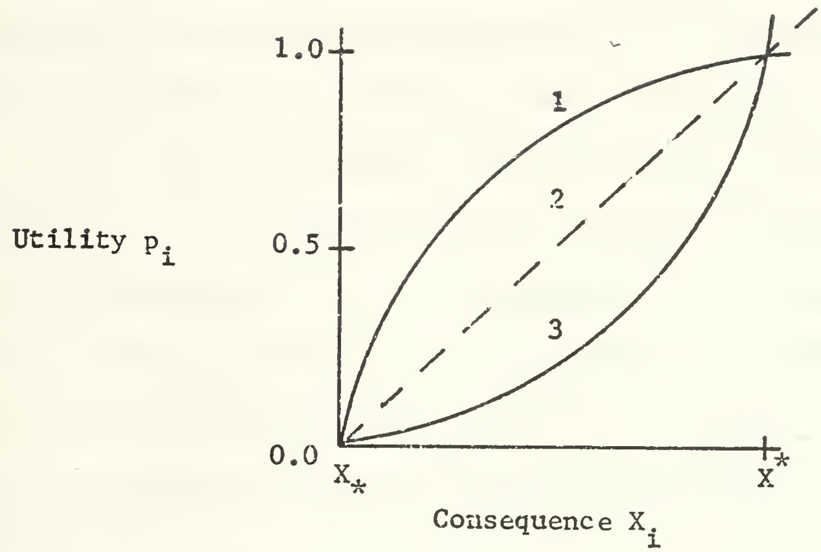


Figure 2. Examples of Utility Curves.

assessment scheme is impractical. First, too many points must be assessed. Secondly, humans find it difficult to think in terms of multiple attributes. In decision problems under uncertainty, many people, when faced with situations where more than one attribute is relevant, tend to pick the one attribute judged most important to them and then make the decision on that factor alone.

There are procedures for decomposing a multiattributed utility function into combinations of unidimensional functions. Keeney [6] shows that a multiattributed utility function can be expressed in simple additive or multiplicative forms provided the

properties of utility independence, pairwise preferential independence, or pairwise marginality hold. If a utility function of multiple attributes can be expressed in these forms, then the task of defining the utility function is much easier. Suppose $\underline{X} = (x_1,\ldots,x_n)$ describes a consequence where $u(\underline{X})$ denotes the utility of the consequence $\underline{X}$. Utility independence is defined in the following manner. Let $x_{i-} = (x_1,\ldots,x_{i-1},x_{i+1},\ldots,x_n)$. The attribute x_i is utility independent of x_{i-} if the decision-maker's relative preference for x_i, with x_{i-} held fixed, is the same regardless of the actual value of x_{i-} chosen. Order one mutual utility independence is defined to mean that x_i is utility independent of x_{i-} for all i. If order one mutual utility independence holds then $u(\underline{X})$ can be expressed in the quasi-additive form

$$u(x_1,\ldots,x_n) = \sum_{i=1}^{n} c_i u_i(x_i) + \sum_{i=1}^{n}\sum_{j=1}^{n} c_{ij} u_i(x_i) u_j(x_j) + \ldots.$$

Pairwise preferential independence is said to hold if the trade-offs one is willing to make between attributes taken two at a time, are not dependent on the values of the remaining attributes. Let $X_{ij-} = (x_1,\ldots,x_{i-1},x_{i+1},\ldots,x_{j-1},x_{j+1},\ldots,x_n)$, and let x_{ij-} be a particular value from X_{ij-}. The attributes of x_i, x_j are pairwise preferentially independent of X_{ij-} if one's preference order for the consequences $(x_i,\ x_j,\ x_{ij-})$ with x_{ij-} held fixed, does not depend on the particular value x_{ij-}.

If for any pair of attributes x_i and x_j, the lottery $<(x_i,x_j),0.5,(x^0_i,x^0_j)>$ is indifferent to the lottery $<(x_i,x^0_j),0.5,(x^0_i,x_j)>$ then pairwise marginality is said to hold.

With the ideas of utility independence and pairwise preferential independence presented, Keeney's results can be more precisely stated. Let $\underline{X} = (x_1,\ldots,x_n)$ be as previously defined, with $n \geq 3$. If, for some $x_i x_i$ and x_j are pairwise preferentially independent of $(x_1,\ldots,x_{i-1},x_{i+1},\ldots,x_{j-1},x_{j+1},\ldots,x_n)$ for all $j \neq 1$ and x_i is utility independent of x_i-, then either

$$u(\underline{X}) = \sum_{i=1}^{n} k_i \, u_i(x_i) \tag{1}$$

or

$$1 + K\,u(\underline{X}) = \prod_{i=1}^{n} [1 + Kk_i u_i(x_i)] \tag{2}$$

where u and u_i are utility functions scales from zero to one, the k_i are scaling constants with $0 < k_i < 1$ and $K > -1$ is a non-zero scaling constant. Equation (1) is the additive form and Equation (2) is the multiplicative form.

Given that the conditions of Keeney's Theorem hold, he provides a property required to show whether the function is additive (1) or multiplicative (2). He shows that if pairwise marginality holds then the function must be additive; otherwise, it is multiplicative. Table I summarizes the properties necessary for each simplification.

TABLE I. Utility Function Simplification

Simplification	Properties		
	1st order utility indep.	Pairwise preferential indep.	Pairwise marginality
Quasiadditive form	X		
Multiplicative form	X	X	
Additive form	X	X	X

Referring to Figure 1, there are three attributes x_1, x_2 and x_3 which describe each outcome of the tree. For illustration, the following utility function might be used:

$$u(x_1,x_2,x_3) = u(x_1) + u(x_2) + u(x_3) = u_i \ .$$

This utility function, in the additive form, maps the consequences x_1, x_2 and x_3 into a scalar value indicated by u_i, where $i = 1,\ldots,8$, at each branch-tip of the tree.

4. Judgmental Probabilities

The decision-flow diagram is one of the decision analysis methods used in structuring a problem. Utility functions can be used for the assignment of preferences for the consequences of the outcomes at each tip of the tree. What remains to complete the information included on the decision-flow diagram is the assignment of the judgmental probabilities at the chance forks representing the uncertain events. This is the third step in the decision analysis process.

Raiffa [4] addresses the question of whether the decision-maker's hunches or value impressions should be calibrated, and if so, how this should enter into the formal decision analysis process. He argues that if a decision-maker wishes to act consistently, then he ought to assign values to judgmental probabilities such that the sum of the probabilities of an event occurring and not occurring equals one. This judgmental probability assessment for an event should not depend on the outcomes. He points out that judgmental probabilities satisfy the usual rules of probability theory and can be used in the same manner as objective probabilities.

Judgmental probabilities are used as a measure of the decision-maker's beliefs concerning the uncertainty of an event occurring, provided that these beliefs are consistently applied to every uncertain event in the analysis. They are assigned to each chance fork of the tree. In Figure 3, they are represented as p_1, $1-p_1$, p_2, $1-p_2$, p_3, $1-p_3$, p_4, and $1-p_4$. With this information, the final step in any iteration of the decision analysis process is to determine the recommended course of action.

5. Recommended Course of Action

Determination of the recommended course of action involves a sequence of calculations called the "averaging out and folding back" procedure. This procedure is often referred to as the process of backwards induction in the theory of dynamic programming. The procedure starts at the tips of the tree and consists of computing the expected utility of each chance fork and the selection of the greatest utility at each decision fork. The process is repeated for each level of the tree until the starting decision fork is reached. The alternative with the greatest expected utility is selected as the recommended course of action. The selection of the maximum expected utility is an appropriate means of determining actions consistent with the decision-maker's attitudes and opinions.

To illustrate the "averaging out and folding back" process, the information contained in Figure 1 is used. Starting at the chance fork labeled 1, the expected utility is computed as

$$u_1 p_3 + u_2 (1 - p_3) = E_1$$

Moving backwards in the tree, the next fork encountered is a decision fork, labeled $\boxed{2}$. The value of E_1 or u_3, whichever is greater, is selected. For illustration, E_1 is selected. Continuing backwards through the tree, a chance fork, labeled 3, is encountered. At this point, the expected utility of the chance fork is computed as

$$E_1 \, p_1 + u_4 \, (1 - p_1) = E_2 \, .$$

Alternative I has now been reached and the expected utility of this alternative is E_2. In similar fashion, the expected utility of alternative II is computed. The results are compared and the alternative with the greatest expected utility is selected as the recommended course of action.

C. SUMMARY OF THE CHAPTER

Formal analyses of specific diagnostic categories are seen as a substantive source for diagnosis-treatment procedures. Specific diagnostic categories are uncertain and multiattributed. A formal analysis technique must be able to cope with uncertainty and multiple outcomes.

Decision analysis has been presented as a formal technique that is highly effective when applied to uncertain, multiattributed problems. Decision analysis methodology has been developed, and it provides a foundation for a decision analysis of the diagnostic category of hypertension.

III. THE SPECIFIC DIAGNOSTIC CATEGORY OF HYPERTENSION: TEST AND TREATMENT DECISIONS

"An estimated 23 million Americans, about one in seven adults, have hypertension. This makes hypertension the most common chronic disease in the United States. Half of the people with hypertension don't know they have it. Half of the people who know they have it are not being treated for it. And half of those treated for it are not being treated adequately" [7]. Optimal procedures for diagnosing and treating hypertension would be desirable.

The specific diagnostic category of hypertension is reasonably well-defined in the sense that treatment alternatives and the measures of patient welfare are known. However, no two hypertensives are exactly alike and this complicates the problem. Each hypertensive patient has a unique health profile. This unique profile complicates the formal analysis of hypertension as the uncertainty that occurs in various treatment alternatives is a function of this profile. Theoretically, each hypertensive profile has to be analyzed separately. Clearly, this is not practicable.

The purpose of this chapter is to develop a medical background for hypertension sufficient to state and solve a well-defined hypertensive problem. Accordingly, Section A defines basic hypertension terminology and presents three classifications of hypertension. From these three classifications, sustained diastolic hypertension is selected for further analysis. Section B investigates sustained diastolic hypertension--concentrating on drug regimens typically used to control blood

pressure, surgically correctable causes of sustained diastolic hypertension, and laboratory tests that can detect these surgically correctable causes. Finally, Section C confronts the problem of unique hypertensive patient profiles and states the sustained diastolic hypertension problem in a well-defined form.

A. MEDICAL BACKGROUND

There are two components of blood pressure - "systolic" and "diastolic." Systolic pressure occurs when the heart contracts and is the higher of the two pressures. Diastolic pressure occurs during dilation or expansion of the heat [8]. Readings of blood pressure are typically made of both figures. For example, a typical blood pressure report is 120/80 mm Hg where 120 is the systolic pressure and 80 is the diastolic pressure.

There are two classifications for the disease of hypertension - "secondary" and "essential." Secondary hypertension is the result of a <u>known</u> cause while essential hypertension represents hypertension for which there is no known cause. Essential hypertension comprises about 90 percent of the hypertensive population [9].

When a resting supine adult has an arterial pressure of 160/90 mm Hg or higher, hypertension is considered to be present. However, hypertension can be further subclassified into three groups, including: labile, systolic, and diastolic. Labile hypertension occurs when a patient's blood pressure checks high on one visit but then returns to normal on subsequent visits. Patients with intermittently high and normal blood pressure should be reexamined at regular intervals as labile hypertension often develops into sustained hypertension [9].

Sustained systolic hypertension exists when the systolic blood pressure is abnormally high (usually greater than 160 mm Hg), but the diastolic blood pressure is normal (usually less than 90 mm Hg). Sustained systolic hypertension often suggests particular causes, such as aortic insufficiency and arteriosclerosis [9]. Prognosis, and therefore treatment, of systolic hypertension lacks consensus among health physicians. Harrison [9] says, "the treatment of isolated systolic hypertension is not recommended." However, Koch-Weser [10] states "it is no longer reasonable to accept that systolic hypertension can and must be therapeutically ignored." The results of well-controlled prospective studies geared to measuring the prognosis of this case are needed.

Sustained diastolic hypertension is defined as diastolic blood pressure greater than 90 mm Hg. One type of sustained diastolic hypertension is malignant hypertension. The patient with malignant hypertension often has blood pressure above 200/140 mm Hg. But it is the papilledema (abnormal accumulation of fluid in the eyes), not the level of blood pressure, that specifically defines malignant hypertension. Malignant hypertension has serious health consequences. As a result, diagnosis-treatment procedures for this disorder are relatively standard, including extensive laboratory work-ups and immediate treatment [9].

Sustained diastolic hypertension that is not malignant (hereafter referred to as sustained diastolic hypertension) is selected as the focus for a decision analysis because:

1. this type of hypertension represents the majority of hypertensive cases;

2. there is consensus among doctors that uncontrolled sustained diastolic hypertension can cause vascular disease, organ damage, and premature death; and

3. determinations of when to use certain laboratory tests that can detect surgically correctable causes of sustained diastolic hypertension have not been established.

B. SUSTAINED DIASTOLIC HYPERTENSION

A convenient way to discuss sustained diastolic hypertension is to subdivide it into smaller categories. First, sustained diastolic hypertension is divided into essential diastolic hypertension and secondary diastolic hypertension. Next, secondary diastolic hypertension is broken down into cases having surgically correctable causes and into cases having nonsurgically correctable causes. This classification scheme is presented in Figure 3 [11].

The physician who treats sustained diastolic hypertension must, in effect, treat the various categories presented in Figure 3. All of these categories can normally be effectively treated with drugs. Hypertensive drug therapy currently being used is relatively standard. Conn[12] recommends the drug program given in Table II.

TABLE II. Drug Treatment for Hypertension

Diastolic Blood Pressure (dbp), mm Hg	Initial Therapy	Secondary Therapy
90 < dbp < 110	Oral Diuretic	Methyldopa or Hydralazine
110 < dbp < 130	Oral Diuretic and Methyldopa	Hydralazine

New drugs are beginning to emerge (e.g., inderal), but today most hypertensives are still being treated with the drugs shown in Table II.

- Sustained Diastolic Hypertension
  - Essential Diastolic Hypertension
  - Secondary Diastolic Hypertension
    - Nonsurgically Correctable Causes:
      1. Obesity
      2. Oral Contraceptives
      3. Pregnancy
      4. Polyphyria during acute attack
      5. Lead poisoning during acute phase; etc.
    - Surgically Correctable Causes:
      1. Renal vascular disease
      2. Primary aldosteronism
      3. Pheochromocytoma
      4. Cushing's Syndrome
      5. Coarctation of the aorta

Figure 3. Sustained Diastolic Hypertension Categories

Each of these drugs can have unpleasant side-effects. Oral diuretics usually have negligible side-effects but can cause mild drowsiness. Methyldopa can produce drowsiness, dry mouth, mood disturbances, and fever. And hydralazine can cause headaches, arthritis, and fever [12]. However, most people experience very few of these side-effects, and the physician can generally find some combination of these drugs that will successfully control hypertension and cause very minor side-effects [13].

A category of sustained diastolic hypertension where the physician has several diagnosis-treatment options is surgically correctable diastolic hypertension. The ideal treatment for this category, assuming the patient is an acceptable surgical risk, is surgery. However, laboratory tests are generally required to expose surgically correctable causes. To develop an adequate understanding for this hypertensive category, surgically correctable causes of sustained diastolic hypertension are discussed.

Pheochromocytoma is a relatively rare phenomenon caused by tumors that are developed by cells from the adrenal glands. Ninety-five percent of these tumors are located in the abdomen [9]. About .5 percent of the hypertensive population (all patients with sustained diastolic hypertension) are believed to have these tumors [14]. Surgery generally consists of a careful abdominal examination through a generous traverse upper abdominal examination. Surgery results in a complete remission of symptoms unless multiple tumors exist [9].

Primary aldosteronism sometimes referred to as Conn's Syndrome, usually results from a benign tumor of the adrenal gland. Treatment

is surgery exploring both adrenal glands. After successful removal of aldosterone producing tumors, 70 percent of the patients became normatensive, 25 percent have a significant lowering of their blood pressure, and five percent have no change [9]. This condition is believed to be surgically correctable in about one percent of the hypertensive population [14].

Cushing's Syndrome is a rare disorder that is often a result of adrenal tumors. These tumors exist in about .4 percent of the hypertensive population [14]. Cushing's Syndrome can also be caused by other abdominal tumors and pituitary malfunctions. Surgery is the only completely satisfactory treatment for adrenal tumors [9]. Successful surgical corrections for other abdominal tumors and pituitary malfunctions have been rare [11].

Renal hypertension is the most common type of potentially curable hypertension. The two subdivisions of renal hypertension are renal arterial hypertension and renal parenchymal hypertension [15]. Surgically correctable forms of these two internal disorders occur in about 4 percent of the hypertensive population [14]. Renal arterial hypertension occurs when a major renal artery becomes constricted, decreasing blood flow to that kidney. Treatment consists of surgery where the constricted portion of the artery is removed. Parenchymal hypertension occurs when the smaller blood vessels in the kidney cease to function properly. Surgical correction for this disease usually requires complete removal of a kidney and, hence, can only be done when the disease is unilateral. Surgical treatment for renal arterial constriction and for unilateral parenchymal disease usually results in a normotensive patient [9].

Coarctation of the aorta results from a physical abnormality in the aorta causing a decrease in blood flow to the lower portion of the body [15]. Coarctation of the aorta is responsible for about one percent of the hypertensive population [14]. Surgery is the ideal cure in these cases [9].

Surgery for the above internal disorders requires the patient spend about eight days as an inpatient, followed by three weeks of sedentary activity [16]. This, of course, assumes no surgical complications.

Having developed an understanding for surgically correctable causes of sustained diastolic hypertension, the question now becomes, "How can one detect these causes?" Harrison [9] recommends a basic set of laboratory tests as a first step when it is desired to investigate for surgically correctable causes of sustained diastolic hypertension. This particular set of tests is suggested because collectively the tests investigate all surgically correctable causes, and all tests can be administered in one day as an outpatient. The individual tests, and the surgically correctable causes they investigate are given in Table III. Test effectiveness is given for primary test indicators.

If a hypertensive patient has basic test indications that suggest a surgically correctable disorder, auxiliary tests are normally conducted. These auxiliary tests are specifically designed for the five surgically correctable disorders and are performed on an inpatient basis. They require about two days in the hospital. A positive auxiliary test is virtually always followed by surgery [16].

TABLE III. Basic Laboratory Tests

A. Urine

1. urinalysis: renal
2. urine culture: renal
3. 24 hr. catacholamines: presence indicates 90% chance of pheochromocytoma

B. Serum

1. Na, K, Cl, CO_2: low K indicates 50% chance of primary aldosteronism
2. Creatinine: renal
3. Fasting sugar and 24 hr. postprandial sugar: pheochromocytoma
primary aldosteronism
Cushing's Syndrome

C. Other

1. ECG: general health
2. X-RAY: coarctation of aorta
general health
3. Rapid sequence intravenous pyelogram: 90% reliable in detecting surgically correctable renal vascular disease

C. TEST AND TREATMENT DECISIONS

A physician's first contact with a patient is usually through a clinical evaluation where a patient's history is reviewed and a physical exam is conducted. If this clinical evaluation detects the disease of hypertension, the doctor must decide on subsequent diagnosis-treatment procedures. Table IV [8,9,11] develops the general organization of a clinical evaluation. Specific data are given when they have application for formulating and solving the hypertension problem.

The clinical evaluation is able to substantiate the presence of sustained diastolic hypertension. If sustained diastolic hypertension is due to nonsurgically correctable causes, these causes are normally apparent in the physical exam and can be treated directly. Occasionally, symptoms indicating surgically correctable causes are apparent in the clinical evaluation. If these symptoms are present and the patient is a suitable candidate for surgery, the logical course of action is to administer laboratory tests that can confirm or deny surgically correctable disorders. The fundamental problem confronting the physician is choosing diagnosis-treatment procedures for patients with sustained diastolic hypertension who have no apparent secondary symptoms.

Based on the medical discussion in Section B, there are three options available to the doctor for treating sustained diastolic hypertensive cases with no apparent secondary symptoms - do nothing, investigate for possible surgically correctable causes, or treat hypertension with drugs. This is a problem well-suited for a decision analysis except for the fact that each hypertensive patient has a

TABLE IV. Clinical Evaluation

A. Types of Hypertension

1. normotensive: blood pressure < 90/160 mm Hg
2. labile: intermittently high blood pressure
3. sustained systolic: systolic blood pressure > 160 mm Hg
4. sustained diastolic: diastolic blood pressure > 90 mm Hg
5. malignant: sustained diastolic with papilledema

B. Vital Statistics

1. age
2. sex
3. race

C. General State of Health

1. evidence of vascular disease
2. heart murmurs
3. papilledema

D. History Pertaining to Sustained Diastolic Hypertension

1. family history
    a. heart disease
    b. hypertension
2. patient history - development of hypertension < 35 or > 50 favors surgically correctable hypertension

E. Symptoms and Exam Pattern Pertaining to Sustained Diastolic Hypertension

1. nonsurgically correctable sustained diastolic hypertension
    a. obesity
    b. smoker
    c. pregnancy
    d. oral contraceptives
2. pheochromocytoma
    a. highest incidence in young adults
    b. 50% have intermittent hypertension with sudden attacks of severe headache
3. primary aldosteronism
    a. highest incidence in young adults
    b. occurs in twice as many females as males
4. Cushing's Syndrome
    a. classic symptoms of weight gain and mooning of face observed in about 95% of patients
5. renal vascular disease
    a. highest incidence in older adults
    b. clinical evaluation is of little diagnostic value
6. coarctation of the aorta
    a. weak femural pulse observed in 95% of patients

unique health profile. Blood pressure is a continuum - everyone has blood pressure, but rarely do people have exactly the same blood pressure. And since hypertension is abnormally high blood pressure, rarely do hypertensive patients have the same level of hypertension. Furthermore, hypertension occurs in patients who have different ages and degrees of general health making a given level of hypertension more serious in one person than in another. This results in a different health prognosis for each hypertensive patient.

To understand the impact of unique health patient profiles on a decision analysis, the mechanics of decision analysis presented in Chapter II are reviewed. Recall that a part of the decision analysis formulation consists of determining the possible outcomes or consequences for selected alternatives and obtaining the probability that these consequences will occur. When each hypertensive patient has a unique health profile, the probability that a given consequence will occur is different for each patient. As a result, each hypertensive patient theoretically requires an independent analysis.

To make this problem tractable, this infinite number of possible health profiles must be divided into a finite number of discrete health profiles. To develop discrete health profiles, one must identify what factors in a patient's health profile affect the probability that possible consequences will occur. Once these factors are identified, they can be put into discrete forms that will provide the basis for discrete health profiles.

Identifying factors that affect the probability that consequences will occur requires that one be aware of these consequences. The

detailed development of alternatives and their consequences is done in Chapter IV where the problem is formulated. However, the problem as it now stands is relatively well-defined and these consequences can be discussed in general terms. In the case of hypertension, the consequences are measures of patient welfare that must be simultaneously considered with each alternative. These consequences can be logically divided into factors related to health and factors related to cost. Factors related to cost include such things as the cost of tests, surgery, and drugs; factors related to health include such things as surgical complications, and organ damage and premature death if blood pressure is not controlled.

The logical source for factors that affect the probability of occurrence of cost and health consequences is the clinical evaluation. The clinical evaluation probes most aspects of hypertensive patient profiles, and the content of this evaluation is available to the decision-maker a priori. Inspection of Table III gives five factors that affect the probable occurrence of cost and health consequences. These factors are surgically correctable symptoms, sex, age, level of diastolic hypertension, and the general state of health of the patient. Patients with surgically correctable secondary symptoms have a higher probability of obtaining a surgical cure for their hypertension. Women tolerate high blood pressure better than men and, as a result, have less chance of health complications when high blood pressure is not controlled. The age of the hypertensive patient directly affects the probable occurrence of health and cost outcomes. A young patient with uncontrolled high blood pressure is more likely to experience severe health complications than an older patient with the same level

of blood pressure. And a young patient being treated for hypertension by drugs will probably incur more expense for medication during the course of a normal life than an older patient. The level of diastolic pressure clearly affects the prognosis of the untreated patient. A patient at a certain age with a high level of diastolic blood pressure will probably experience more severe organ damage and a greater reduction in longevity than a man at the same age with a lower diastolic blood pressure. The general state of health of a patient affects the probability that surgical complications will occur if surgery is performed.

Having identified five factors that affect the probabilities of cost and health consequences, the next step is to divide these five factors into discrete ranges. The general state of health of a patient is very difficult to divide into discrete levels since there are so many variables involved in a person's general health. As a result, this paper simply considers hypertensive patients to be either a low surgical risk or not a low surgical risk. Surgically correctable symptoms are also difficult to divide into discrete ranges, since the scope of possible symptoms is infinite. This paper treats surgically correctable symptoms as either existing or not existing. Age is divided into three groups - less than 35, 35 to 50, and older than 50 years of age. These categories are chosen because hypertensive patients less than 35 and greater than 50 are more likely to have surgically correctable hypertension.

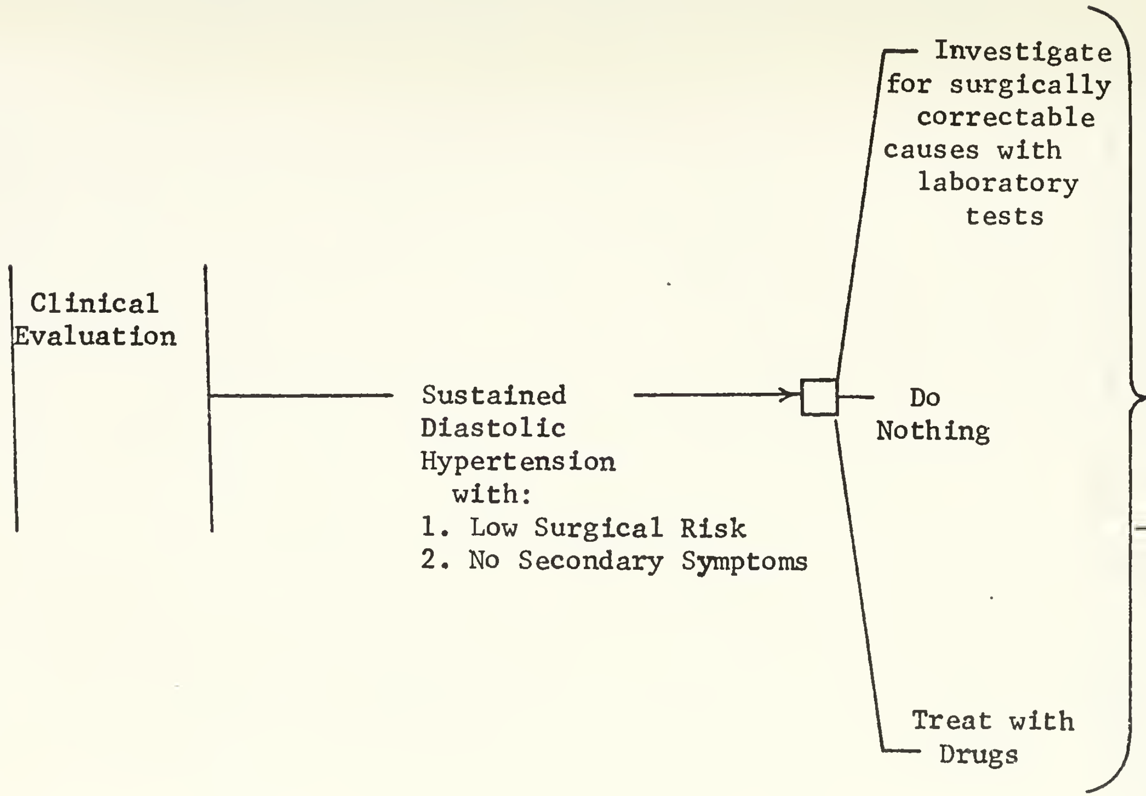
Sustained diastolic hypertension represents all blood pressures greater than 90 mm Hg. This paper assumes diastolic blood pressures

greater than 120 mm Hg fall into the malignant category as these cases require immediate treatment, and the seriousness of the disease justifies elaborate laboratory work-ups. As a result, patients with diastolic blood pressures over 120 mm Hg are excluded from the problem. The term "sustained diastolic hypertension" now refers to diastolic blood pressure between 90 and 120 mm Hg. This range of blood pressure is divided into two smaller groups, 90 to 105 mm Hg and 105 to 120 mm Hg.

There are 48 possible combinations of the preceding subdivisions of the five factors that affect the probable occurrence of health and cost outcomes. These 48 combinations represent 48 discrete hypertensive profiles. Not all of these profiles are appropriate for a decision analysis. Patients with surgically correctable symptoms have already been excluded from the scope of the problem as it is assumed that the logical alternative for these patients is to perform laboratory tests. And patients observed to be other than a low surgical risk are excluded from the analysis as their treatment depends on the general state of health of the patient. This results in six male and six female hypertensive profiles suitable for a decision analysis. These profiles are three age groups each of which has two blood pressure groups for low surgical risk patients with no secondary symptoms. The resulting problem to be solved is illustrated in Figure 4.

D. SUMMARY OF THE CHAPTER

Sustained diastolic hypertension has been selected for a decision analysis application. A decision analysis of sustained diastolic hypertension requires that one be able to cope with unique hypertensive



(3) Options analyzed for both men and women in the following (6) discrete health profiles:

Age, Years	Blood Pressure, mm Hg
1. ≤ 35	90 - 105
2. 35-50	"
3. >50	"
4. < 35	105-120
5. 35-50	"
6. >50	"

Figure 4. Test and Treatment Options

patient profiles. As a result, this chapter has developed 12 discrete hypertensive profiles suitable for a decision analysis.

The problem to be formulated in Chapter IV can be briefly stated as follows:

> If a patient has sustained diastolic hypertension, is a low surgical risk, and has no secondary symptoms, the physician has three options. These options are to do nothing, to investigate for surgically correctable causes for the hypertension, or to treat the hypertension with drugs. These three options are analyzed for men and for women in each of six age/blood pressure groups.

IV. PROBLEM FORMULATION

Decision analysis methodology developed in Chapter II gives three steps required for problem formulation. These steps are:

1. to structure the problem,
2. to establish preferences for outcomes, and
3. to obtain judgmental probabilities.

Structuring the problem is done in three steps. First, all problem alternatives are enumerated. These problem alternatives are based on the medical discussion of hypertension given in Chapter III. Secondly, all uncertain events for these alternatives are noted. The final step is to assemble the alternatives and their events in a chronological order. The ultimate objective in structuring the problem is to develop the alternatives and events in a decision tree.

Establishing preferences is done in two steps. All possible consequences of the decision alternatives are obtained. Then multidimensional utility theory is applied to these multiple consequences to reduce them to a single level of effectiveness.

The final step of problem formulation is to assess judgmental probabilities for all uncertain events. These probabilities are obtained from medical statistics given in Chapter III and from informal physician interviews.

A. STRUCTURING THE PROBLEM

The first step in structuring a problem is to identify all alternatives available to the decision-maker. A logical starting point for

identifying treatment alternatives is to examine the three treatment options developed in Chapter III. Based on the discussion of test and treatment procedures given in Chapter III, each of these three treatment options implies an initial alternative. The treatment options and their corresponding initial alternatives are given in Table V.

TABLE V. Treatment Options and Initial Alternatives

Option	Initial Alternative
Investigate for Surgically Correctable Causes	Perform Basic Tests (Table III)
Treat with Drugs	Administer Standard Drug Sequence (Table II)
Do Nothing	Do Nothing

If basic tests are performed, there are two additional alternatives available to the doctor - perform auxiliary tests and conduct surgery. As a result, for the three treatment options, there are five possible alternatives: perform basic tests, perform auxiliary tests, conduct surgery, administer drugs, and do nothing.

Now that treatment alternatives are identified, the next step in structuring the problem is to obtain the uncertain events that can occur as a result of these alternatives. The uncertain events for each of the five preceding alternatives are developed in two steps. First, general events to the specific alternatives are given. These general events are a basic description of logical possible outcomes of the alternatives. Then if the general events are not sufficiently specific for a decision analysis, they are analyzed within the medical context

of the alternative they represent and restated in more specific terms. During this process, an attempt is made to represent all specific events as concisely as possible, thereby keeping the problem structure simple. Alternatives, general events, and specific events are given in Table VI.

Most general events are sufficiently specific to be used in the actual analysis. The general event of an equivocal result from a basic set of tests or from auxiliary tests is eliminated as it is assumed that the doctor can resolve these cases to either positive or negative results.

Two general events that must be put into more specific terms are surgical complications and drug complications. These two general events are alike in that they each imply many possible specific events. Drug complications can be anything from mild drowsiness to chronic depression to violent reactions. And surgical complications include prolonged convalescence, morbidity, and mortality. This paper assumes that a patient with sustained diastolic hypertension will not continue taking a drug that causes side-effects worse than mild drowsiness. Furthermore, 30 days is viewed as enough time to try all possible drugs in an attempt to overcome undesirable side-effects. As a result, unacceptable side-effects are viewed as drug side-effects worse than mild drowsiness that cannot be corrected in 30 days. Surgical complications for low surgical risk patients undergoing routine abdominal surgery are rare. Most patients experience a standard convalescence. Occasionally a patient dies during surgery. However, a patient very rarely incurs a permanent or prolonged disability. Therefore, the only

TABLE VI. Alternatives, General Events, Specific Events

Alternative	General Event	Specific Event
Basic tests	Positive, negative, (or) equivocal	Negative (or) positive
Auxiliary tests	Positive, negative, (or) equivocal	Negative (or) positive
Drugs	Blood pressure control (or) no blood pressure control	Blood pressure control (or) no blood pressure control
	Drug complications (or) no drug complications	Unacceptable side effects (or) acceptable side effects
	Patient continues drugs (or) patient discontinues drugs	Patient continues drugs (or) patient discontinues drugs
Surgery	Blood pressure control (or) no blood pressure control	Blood pressure control (or) no blood pressure control
	Surgical complications (or) no surgical complications	Death (or) no surgical complications
Do nothing	No blood pressure control	No blood pressure control

specific surgical complication considered in the problem structure is death.

The ultimate goal of this section is to represent the structure of the problem in a decision tree. To do this, the chronological ordering of the five alternatives must be established. The initial alternative for each of the decision options was given in Table V. But the chronology of subsequent alternatives is not definite. Theoretically, any of the remaining four alternatives can follow the initial alternative for each option. However, not all of these alternative chronologies are logical. The chronology for the option of doing nothing can be disposed of quickly as this option has but one alternative and is obviously an end in itself. The chronology for the other two options is based on the following assumptions:

1. If basic tests are conducted and the tests are positive, it is assumed that auxiliary tests are performed.

2. If auxiliary tests are positive, it is assumed that surgery is performed.

3. If the basic tests are negative, if the auxiliary tests are negative, or if the surgery fails to control the high blood pressure, and if drugs have not been previously administered, it is assumed that drugs are administered in an attempt to treat the hypertension.

4. If the basic tests are negative, if the auxiliary tests are negative, or if surgery fails to control the high blood pressure, and if drugs have been previously tried and found to be unsatisfactory, it is assumed that there is no blood pressure control.

5. If drugs are administered and the drugs either have unacceptable side-effects or do not control the high blood pressure, and if basic tests have not been previously conducted, it is assumed that basic tests are performed.

6. If drugs are administered and the drugs either have unacceptable side-effects or do not control the high blood pressure, and if basic tests have been previously performed, it is assumed that there is no blood pressure control.

7. If drugs control the high blood pressure,and the drugs have acceptable side-effects, but the patient discontinues the drugs, it is assumed there is no blood pressure control.

8. If drugs control the high blood pressure and the drugs have acceptable side-effects, and the patient continues the drugs, it is assumed that there is blood pressure control.

Blood pressure control and no blood pressure control as used in the above assumptions denote a condition that exists throughout the remaining life of the patient.

If the five alternatives are ordered for the three treatment options using the preceding ordering assumptions, the treatment options terminate in one of the following three events: blood pressure control, no blood pressure control, or death. The two events of blood pressure control and no blood pressure control are not suitable for terminating alternative orderings as they imply subsequent outcomes. The possible outcomes of these two events must be understood before the problem can be analyzed.

A logical way to terminate the outcomes of blood pressure control and no blood pressure control is to decide whether they cause health complications or they don't cause health complications. This paper assumes there are no health complications if there is blood pressure control, and there are health complications if there is no blood pressure control. As a result, the three events of death, health complications and no health complications provide a well-defined termination for all possible alternative orderings.

The general event of health complications must be put into specific terms. Health complications are like drug and surgical complications in the sense that these general events imply many possible specific

events. Untreated hypertensives can experience irreparable damage to the eyes, heart, and kidneys. However, the most significant prognosis of uncontrolled high blood pressure is premature death. As a result, this paper uses reduction in normal life as the sole specific event for health complications. Table VII [17] gives life expectancies for the 12 health profiles.

TABLE VII. Life Expectancies

Age (years)	Diastolic Blood Pressure mm Hg	Life Expectancy (years) Male	Female
< 35	< 90	77	82
	90 - 105	60	67
	105 - 120	(48)	(55)
35-50	< 90	77	82
	90 - 105	68	75
	105 - 120	(56)	(63)
> 50	< 90	77	82
	90 - 105	73	79
	105 - 120	(65)	(70)

( ) are extrapolated values.

Based on the preceding discussion, the alternatives and events for the three treatment options are now chronologically arranged in a decision tree given in Figures 5, 6, and 7. The specific events of no blood pressure control and unacceptable side-effects for the drug alternative have been combined into "other" as the distal portions of the tree for these two events are the same. Note that although there are five alternatives, the problem structure has only three strategies, one for each of the treatment options.

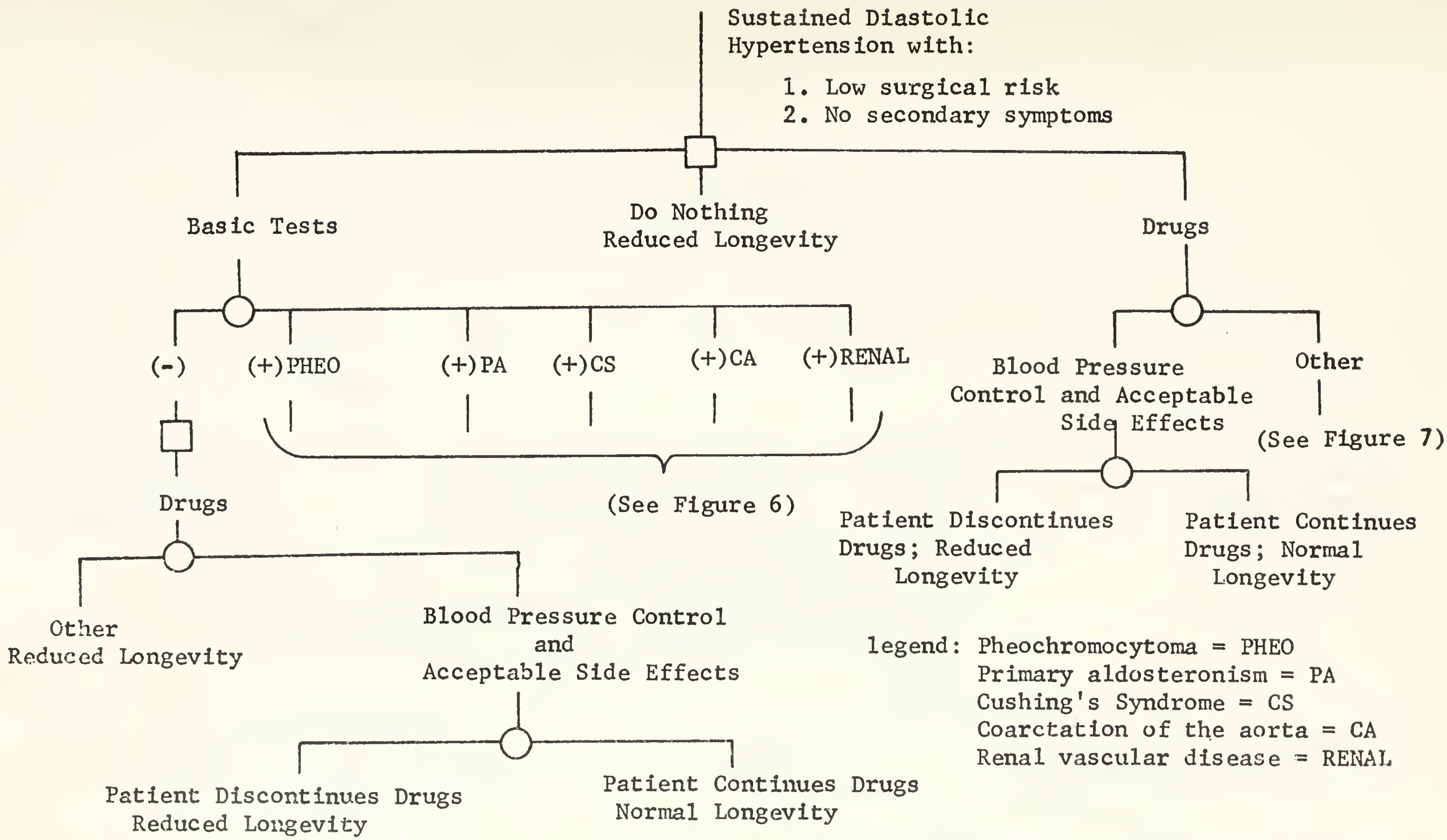
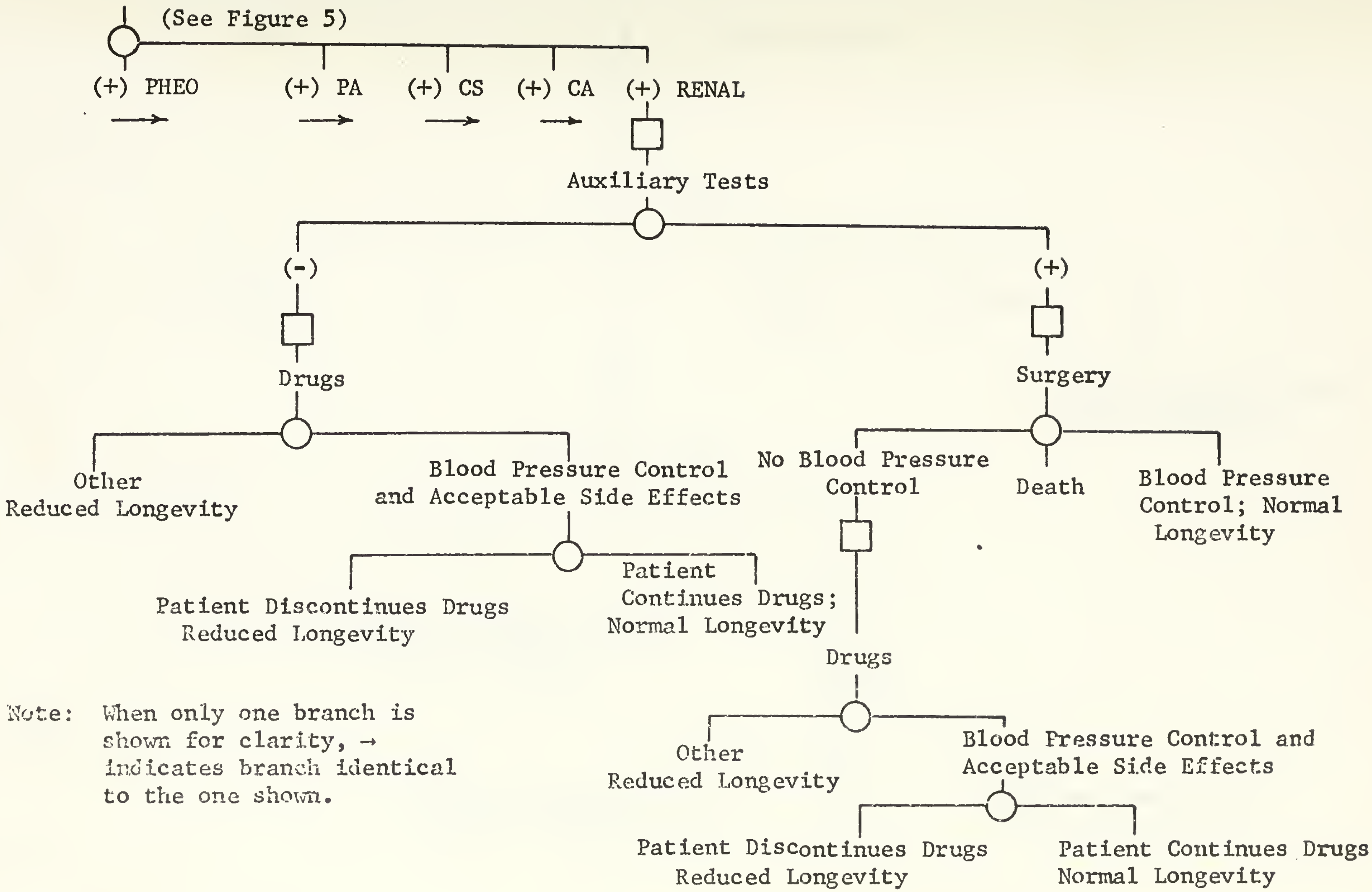


Figure 5. Decision Tree



Note: When only one branch is shown for clarity, → indicates branch identical to the one shown.

Figure 6. Decision Tree (Continued).

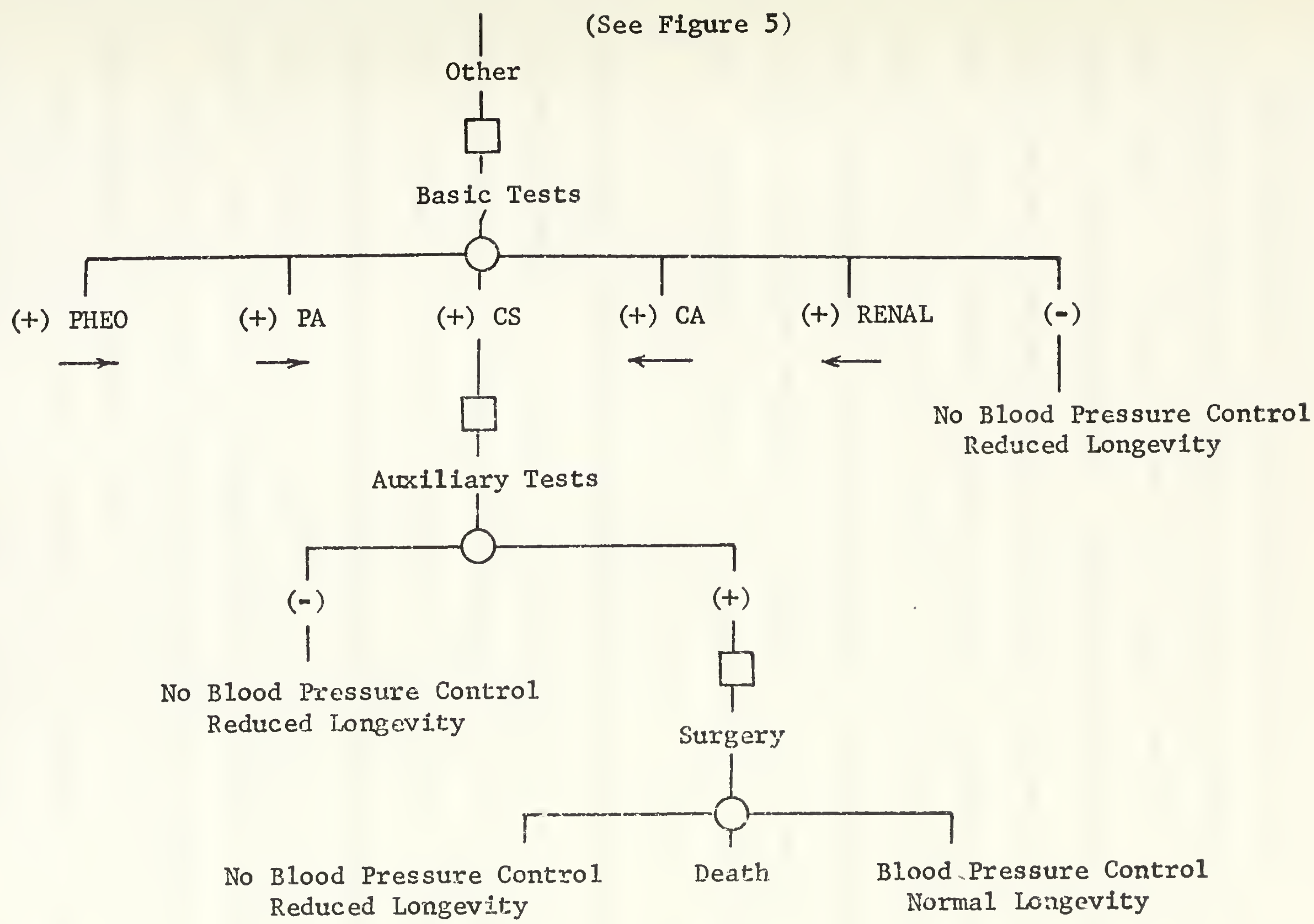


Figure 7. Decision Tree (Continued).

B. ESTABLISH PREFERENCES

Before discussing how multidimensional utility theory can be used to formulate outcome preferences, it is best to dispense with some preliminaries. First, two terms that occur throughout this section are "analyst" and "decision-maker." The analyst is the party who identifies treatment alternatives and the possible outcomes of these alternatives. Having identified possible outcomes, the analyst then obtains a relative measure for these outcomes by assessing decision-makers, where decision-makers are parties who have an interest in possible outcomes. The author performs the functions of the analyst in this paper. Theoretically, there are three categories of decision-makers: the patient, the doctor, and the public sector. However, to limit the analysis, this paper analyzes hypertension using only the patient as the decision-maker. Secondly, a military installation is selected for the environment of the hypertensive analysis. This environment is chosen because local military doctors are interested in optimal hypertensive diagnosis-treatment procedures for military personnel. In this military installation, the government finances all medical services. As a result, the patient incurs no medical charges.

Giauque [18], in his work on upper respiratory infection, successfully used multidimensional utility theory to obtain single measures of effectiveness for decision outcomes. The technique developed in his work is applicable to the problem of hypertension and, therefore, is used in this paper. Accordingly, this section is a recapitulation of Giauque's technique, and is presented only to the extent necessary to solve the hypertension problem. It is specifically designed for

the case where the patient is the decision-maker and the government is the sole provider.

The first step in obtaining outcome preferences is to develop a result vector. A result vector is composed of several dimensions. Each dimension is composed of components. Together, these components represent all possible consequences of the problem. The unique quality of a dimension is that it has one, and only one, of its components in each tree branch. A straight-forward method of obtaining dimensions and their components is to examine branches of the decision tree given in Figures 5, 6, and 7, noting all possible dimensions and components. This examination reveals five dimensions and 12 components. These dimensions and their components complete the result vector, and are given in Table VIII.

Dimension components normally have consequences concerning both cost and health. The health and cost consequence for each component is given in Table VIII. Health factors are based on the medical discussion of hypertension given in Chapter III and Section A of this chapter. Costs are primarily based on Army Regulation No. 40-330 [19], which gives rates for Army medical department activities. When cost data are not available in this regulation, medical costs from the private sector are used.

Now that the result vector has been developed, multidimensional utility theory is applied to the result vector. The goal of this application is to reduce the result vector to one measure of effectiveness.

TABLE VIII. Result Vector--Dimensions, Components and Health and Cost Consequences

Dimension	Component	Consequences: Health	Consequences: Cost ($)
Basic tests	Basic tests	(1) day-outpatient	140
	No basic tests	Perfect health	0
Auxiliary tests	Auxiliary tests	(2) day-inpatient	260
	No auxiliary tests	Perfect health	0
Drugs	Pills	Pills 2/4 times/day; mild drowsiness	1000*
	Unacceptable side effects	(30) days - depression	5
	No drugs	Perfect health	0
Longevity	Low reduction in longevity	Table VII	0
	High reduction in longevity	Table VII	0
	Normal longevity	Table VII	0
Surgery	Death	Death	0
	Routine surgery	(8) day-inpatient; (3)week-sedentary	1200
	No surgery	Perfect health	0

*Cost figure for patient taking pills for 35 years

Pairwise marginality holds between health and cost consequences. This can be represented as

$$u(\underline{x}) = K_T\, u_h(\underline{x}_h) + (1 - K_T)\, u_c(\underline{x}_c) \tag{3}$$

where $u(\underline{x})$ is a single measure of effectiveness of the result vector, and x_h and x_c refer to health and dollar consequences.

Pairwise marginality also holds among costs to the patient, the doctor, and the public sector. This can be expressed as

$$u_c(\underline{x}_c) = K_p u_p(x_p) + K_d u_d(x_d) + K_g u_g(x_g) \tag{4}$$

where x_p, x_d, and x_g represent costs to the patient, the doctor, and the government. Since the government is paying for all medical services, x_p and x_d are zero. This results in

$$u_c(\underline{x}_c) = K_g u_g(x_g) \tag{5}$$

where K_g expresses the patient's concern for governmental medical costs. This paper assumes K_g is zero. As a result,

$$u_c(\underline{x}_c) = 0 \text{ , and} \tag{6}$$

$$u(\underline{x}) = u_n(\underline{x}_h) \text{ .} \tag{7}$$

Stated in words, when the patient is the decision-maker and the government is financing the medical services, health consequences are the only relevant components of the result vector.

To obtain the utility structure for the health vector, the analyst must examine each dimension of the health vector taking all combinations of dimensions two at a time, to determine which, if any, of the characteristics of first order utility independence, pairwise preferential independence, and pairwise marginality hold for each combination.

Pairwise marginality between two dimensions implies indifference between such gambles as

$$\langle (x_{11}\ x_{21}),\ (x_{12}\ x_{22}) \rangle^{*} \quad \text{and}$$

$$\langle (x_{11}\ x_{22}),\ (x_{12}\ x_{21}) \rangle ,$$

where x_{11} and x_{12} are consequences of one dimension and x_{21} and x_{22} are consequences of a second dimension. Pairwise marginality was found to hold between all possible combinations of the following four dimensions: basic tests, auxiliary tests, drugs, and longevity. The tests used to justify pairwise marginality between all combinations of these dimensions are not reproduced in this paper. However, an example is done to illustrate the method. Choose the dimensions of auxiliary tests and drugs. The author considers the gamble of

$$\langle \text{(auxiliary tests, pills), (no tests, no pills)} \rangle$$

sufficiently close to being equivalent to the gamble of

$$\langle \text{(auxiliary tests, no pills), (no tests, pills)} \rangle .$$

Pairwise marginality was decided not to hold between the dimension of surgery and all other dimensions. For example, clearly the gamble of

$$\langle \text{(death, no pills), (no surgery, pills)} \rangle$$

---

*The notation < A,B > denotes a gamble with a 50% chance of A or B.

is less preferred than the gamble

$$\langle \text{(death, pills), (no surgery, no pills)} \rangle .$$

However, pairwise preferential independence and utility independence seemed appropriate between the dimension of surgery and all other dimensions. Again, not all combinations are tested here but an example is given to demonstrate the technique. Compare the relationship of the drug dimension to the surgery dimension. Would the price one would be willing to pay, in terms of drug side-effects and the inconvenience associated with taking drugs, to avoid routine abdominal surgery, depend on the particular levels of other consequences? Also, do one's feeling about the relative unattractiveness of routine abdominal surgery depend in any way on the amount of drug side-effects? If the answers to these and similar questions is "no," or even "almost no," the assertion of utility independence and pairwise preferential independence is justified or "almost justified" for this particular combination of dimensions. The answers to these questions and similar questions are matters of opinions, but it seemed reasonable to assume the answers justified the independence properties stated above.

To summarize, the health utility interrelationships as viewed by the author are:

1. pairwise marginality holds between all combinations of the four dimensions of basic tests, auxiliary tests, drugs, and longevity, and

2. pairwise preferential independence and utility independence holds between the dimension of surgery and each of the above four dimensions.

With the health utility interrelationships established, the utility function over all five dimensions is now developed.

The additive formula can be used for the four dimensions having the common characteristic of pairwise marginality. The multiplicative formula can be used between the dimension of surgery and the other four dimensions. This results in

$$1 + K\,u(\underline{x}) = [1 + KK_1 u_1(\underline{x}_1)][1 + KK_2 u_2(x_2)] \qquad (8)$$

where $\underline{x}_1$ represents dimensions having pairwise marginality, x_2 is the dimension of surgery, and

$$u(\underline{x}_1) = u_1\,(\underline{x}_1) + u_2\,(x_2)\ . \qquad (9)$$

Since pairwise marginality holds among the dimensions of $\underline{x}_1$,

$$u_1(\underline{x}_1) = \sum_{i=1}^{4} K_{1i}\, u_{1i}\, (x_{1i})\ . \qquad (10)$$

In order to determine the utility function over the entire health consequence space, it is necessary to assess the five unidimensional utility functions and the seven constants that occur in Equations (8) and (10). These data requirements are summarized in Table IX.

To obtain the 12 unknowns in Table IX, two assessments are conducted. First, the analyst assesses all health consequences. Next, patients are assessed on a selected number of health consequences. When these two assessments are complete, they are combined to obtain a reasonably accurate assessment of the patients' attitudes over all health consequences. This procedure permits brief patient interviews

TABLE IX. Data Requirements to Determine Utility Functions

A. Unidimensional Utility Assessments Required

1. basic tests: $u_{11}(\underline{x}_{11})$

2. auxiliary tests: $u_{12}(\underline{x}_{12})$

3. drugs: $u_{13}(\underline{x}_{13})$

4. longevity: $u_{14}(\underline{x}_{14})$

5. surgery: $u_2(\underline{x}_2)$

B. Constants to be Determined by Assessment

1. K, K_1, K_2, K_{11}, K_{12}, K_{13}, K_{14}: constants occurring in the equation decomposing the utility over health dimensions.

and allows the patient to focus on a few key issues, thereby improving the quality of the assessment.

Table VIII gives all consequences of the health vector. There are 13 possible consequences. However, since one consequence in each dimension is equivalent to perfect health, this leaves eight distinct possibilities plus the "perfect health" possibility for a total of nine. The nine possible health consequences are given in Table X, and are ordered from most desirable to least desirable.

The gambles assessed by the analyst are also given in Table X. The gambles are constructed so it is easy for the assessor to think about the gambles. Once the p_i's are assessed, they are adjusted to a high reference of perfect health and a low reference of death. These adjusted probabilities represent the analyst's utility for the health consequence, and are hereafter referred to as UA (.).

TABLE X. Consequences Used for Assessment: Analyst Assessments

Code	Health Consequence	Low Reference	High Reference	p_i*
PH	Perfect health			1
T	Basic tests	AT	PH	p_1
AT	Auxiliary tests	D1	PH	p_2
D1	Unacceptable side effects	S1	PH	p_3
S1	Normal surgery	D2	PH	p_4
D2	Pills	R1	PH	p_5
R1	Low reduction in longevity	R2	PH	p_6
R2	High reduction in longevity	S2	PH	p_7
S2	Death			.01

*p_i is assessed such that the health consequence is equivalent to a p_i chance of the high reference and a $(1 - p_i)$ chance of the low reference.

The health consequences of auxiliary tests, routine surgery and pills are selected for patient assessments as these consequences have a range of utilities that provide a good representation of the complete health vector. The assessment procedure consists of first having the patient order from most desirable to least desirable the three selected consequences.** Next, the analyst assesses gambles over the three consequences of auxiliary tests, routine surgery, and pills in the vector

**If this ordering is inconsistent with the analyst's ordering given in Table IX, the analyst must reorder to remain consistent with the patient.

space bounded by the consequences of perfect health and low longevity. Table XI gives the health consequences used for patient assessments and the gambles used to obtain patient preferences. Note that only three quantities are assessed from the patient: AU1, AU2 and AU3.

TABLE XI. Consequences Selected for Patient Assessment: Patient Assessments

Code	Health Consequence	Low Reference	High Reference	AU_i*
PH	Perfect health			
AT	Auxiliary tests	S1	PH	AU1
S1	Surgery-normal convalescence	D2	PH	AU2
D2	Pills rest of life	R2	PH	AU3
R2	High reduction in longevity			

*AU_i is assessed such that the health consequence is equivalent to an AU_i chance of the high reference and a $(1 - AU_i)$ chance of the low reference.

Once the analyst's assessments and the patients' assessments are complete, the patient assessments over all health consequences are obtained using the interpolation formulas given in Table XII, where U (.) designates utility obtained from interpolation formulas.

TABLE XII. Utility Interpolation Formulas

A. For consequences PH, S2, and R2, assume the same utilities as can be computed from Table X:

$$U(PH) = UA(PH)$$
$$U(S2) = UA(S2)$$
$$U(R2) = UA(R2)$$

B. For consequence
D2: $U(D2) = AU3 \times U(PH) + (1 - AU3) \times U(R2)$
S1: $U(S1) = AU2 \times U(PH) + (1 - AU2) \times U(D2)$
etc., and

C. For intervening consequences, D1 for example:

$U(D1) = F \times U(AT) \times U(S1)$ where
$F = [UA(D1) - UA(S1)]/[UA(AT) - UA(S1)]$

Sufficient data are now available to calculate the five unidimensional health utility functions given in Table IX. Table XIII derives the five functions.

In order to evaluate the seven constants appearing in the health utility function, the U (.) ranking is considered as a multidimensional utility ranking over particular points of the utility space. In particular, consider one of the consequences listed in Table XIV, for instance, consequence D2. In the preceding development, consequence D2 was defined as pills taken two to four times per day for the rest of the patient's life, but implicit in this definition was the idea that everything else was right with the patient. Thus, considering D2 as a point on the multidimensional health space, D2 is more fully described as a point where no basic tests are given, no auxiliary tests are given, no surgery is conducted, the patient lives a normal life, and pills are taken two to four times per day for the rest of the patient's life. Referring then to Table XIII, it can be seen that

TABLE XIII. Derivation of Unidimensional Health Utility Functions

A. Basic tests: $u_{11}(x_{11})$

Two possibilities

1. no basic tests (PH): $u_{111}(PH) = 1$

2. basic tests (T): $u_{112}(T) = 0$

B. Auxiliary tests: $u_{12}(x_{12})$

Two possibilities

1. no auxiliary tests (PH): $u_{121}(PH) = 1$

2. auxiliary tests (AT): $u_{122}(AT) = 0$

C. Drugs: $u_{13}(x_{13})$

Three possibilities

1. no drugs (PH): $u_{131}(PH) = 1$

2. unacceptable side-effects (D1): $u_{132}(D1) = [U(D1)-U(D2)]/[1 - U(D2)]$

3. pills (D2): $u_{133}(D2) = 0$

D. Longevity: $u_{14}(x_{14})$

Three possibilities

1. normal longevity (PH): $u_{141}(PH) = 1$

2. medium longevity (R1): $u_{142}(R1) = [U(R1)-U(R2)]/[1 - U(R2)]$

3. low longevity (R2): $u_{143}(R2) = 0$

E. Surgery: $u_2(x_2)$

Three possibilities

1. no surgery (PH): $u_{21}(PH) = 1$

2. normal surgery (S1): $u_{22}(S1) = [U(S1)-U(S2)]/[1 - U(S2)]$

3. death (S2): $u_{23}(S2) = 0$

at point D2, again considered as a point in multidimensional health space, the utility function u_{133} has a value of zero, while u_{112}, u_{122}, u_{143} and u_{23} have values of one. Other entries in Table XIV are derived in a similar manner.

TABLE XIV. Derivation of Health Utility Constants

Consequence	u_{11}	u_{12}	u_{13}	u_{14}	u_2
PH	1	1	1	1	1
T	0	1	1	1	1
AT	1	0	1	1	1
D2	1	1	0	1	1
R2	1	1	1	0	1
S2	1	1	1	1	0

Recall now the equation for health utilities

$$1 + Ku(\underline{x}) = [1 + KK_1u_1(\underline{x}_1)]\ [1 + KK_2(u_2)] \tag{8}$$

If the values of Table XIV are substituted into (8), then

$$U(PH) = 1 = K_2 + K_1(1+KK_2)(K_{11}+K_{12}+K_{13}+K_{14}) \tag{11}$$

$$U(S2) = .01 = K_1\ (K_{11}+K_{12}+K_{13}+K_{14}) \tag{12}$$

$$U(R2) = K_2 + K_1(1 + KK_2)\ (K_{11}+K_{12}+K_{13}) \tag{13}$$

$$U(D2) = K_2 + K_1(1 + KK_2)\ (K_{11}+K_{12}+K_{14}) \tag{14}$$

$$U(AT) = K_2 + K_1(1 + KK_2)\ (K_{11}+K_{13}+K_{14}) \tag{15}$$

$$U(T) = K_2 + K_1(1 + KK_2)\ (K_{12}+K_{13}+K_{14}) \tag{16}$$

where U (.) are obtained using formulas in Table XII. Since

$$(K_{11} + K_{12} + K_{13} + K_{14}) = 1 , \tag{17}$$

substituting Equation (17) into Equation (12) yields

$$K_1 = U(S2) = .01 \tag{18}$$

Now, substituting Equation (17) into Equation (11) yields

$$K_2 + K_1(1 + KK_2) = 1 \tag{19}$$

As a result, Equations (13), (14), (15) and (16) can be expressed as

$$U(R2) = (K_{11} + K_{12} + K_{13} \qquad) \tag{20}$$

$$U(D2) = (K_{11} + K_{12} \qquad + K_{14}) \tag{21}$$

$$U(AT) = (K_{11} \qquad + K_{13} + K_{14}) \tag{22}$$

$$U(T) = (\qquad K_{12} + K_{13} + K_{14}) \tag{23}$$

Subtracting Equations (20), (21), (22), and (23) from Equation (17) yields

$$K_{11} = 1 - U(T) \tag{24}$$

$$K_{12} = 1 - U(AT) \tag{25}$$

$$K_{13} = 1 - U(D2) \tag{26}$$

$$K_{14} = 1 - U(R2) \tag{27}$$

Equation (19) can be solved for K_2, resulting in

$$K_2 = [1 - K_1] / [1 + KK_1] \tag{28}$$

Substituting Equation (28) into Equation (13) and solving for K yields

$$K = \left\{ [1-U(R2)] - K_1 [1-(K_{11}+K_{12}+K_{13})] \right\} / K_1 [U(R2)-(K_{11}+K_{12}+K_{13})] \qquad (29)$$

Having obtained K, Equation (28) can now be used to obtain K_2.

C. ASSESSMENT OF JUDGMENTAL PROBABILITIES

Probabilities for the uncertain events that occur in the decision tree given in Figures 5, 6 and 7 were obtained by informal interviews with physicians [13, 16] and from medical statistics given in Chapter III.

Table XV is a convenient way to present event probabilities. Using these probabilities, all decision tree probabilities can be determined. For example, if "B" is known, then the probability that auxiliary tests are negative is equal to one minus "B". It is assumed that the probabilities in Table XV do not depend on preceding events unless it is specifically indicated. For example, the probability that the basic tests are positive is valid only if the patient has no secondary symptoms. However, the probability that drugs control high blood pressure and have no unacceptable side-effects is assumed to be constant for all combinations of preceding events.

The probabilities described in Table XV are given in Table XVI for the 12 health profiles and the five surgically correctable causes of sustained diastolic hypertension. The probability of death is assumed to be two percent in all age groups as low surgical risk patients undergoing routine abdominal surgery all have about the same chance of dying during surgery.

TABLE XV. Decision Tree Probability Descriptions

Code	Probability Description
A	- probability that basic tests are positive given that the patient has no secondary symptoms
B	- probability that auxiliary tests are positive given that basic tests are positive
C	- probability that surgery cures high blood pressure given that the auxiliary tests are positive
D	- probability that drugs control high blood pressure and that the drugs do not have unacceptable side-effects
E	- probability of death given that surgery is conducted
F	- probability that the patient continues drugs given that the drugs control high blood pressure and there are no unacceptable side-effects

TABLE XVI. Judgmental Probabilities

Diastolic blood pressure		90 - 120 mm Hg					
Age (years)		< 35		35-50		> 50	
Sex (M=male, F=female)		M	F	M	F	M	F
A	CA	.0005	.0005	.0005	.0005	.0005	.0005
	CS	.0004	.0004	.0004	.0004	.0004	.0004
	R	.04	.04	.03	.03	.06	.06
	PHEO	.005	.005	.0025	.0025	.0025	.0025
	PA	.015	.03	.015	.03	.01	.02
B	R PHEO	.9	.9	.9	.9	.9	.9
	PA	.5	.5	.5	.5	.5	.5
C	R PHEO	.9	.9	.9	.9	.9	.9
	PA	.7	.7	.7	.7	.7	.7
D	R PHEO PA	.98	.98	.98	.98	.98	.98
E	R PHEO PA	.02	.02	.02	.02	.02	.02
F	R PHEO PA	.6	.6	.8	.8	.95	.95

R = Renal
PA = Primary Aldosteronism
PHEO = Pheochromocytoma

CA = Coarctation of Aorta
CS = Cushing's Syndrome

Probability "A" for coarctation of the aorta and Cushing's Syndrome is very small as secondary symptoms for these internal disorders are almost always present in a clinical exam (see Table IV). Based on these low probabilities, coarctation of the aorta and Cushing's Syndrome branches are removed or "pruned" from the decision tree. As a result, the only surgically correctable disorders that enter into the decision analysis are primary aldosteronism, pheochromocytoma, and renal vascular disease.

Probability "F" is assumed to be a function of age as older people are usually more concerned about their health and hence, are more likely to maintain a drug schedule. As a result, it is assumed hypertensive patients less than 35 years of age have a 60 percent chance of continuing drugs, patients between 35 and 50 years of age have an 80 percent chance of continuing drugs, and patients over 50 years of age have a 95 percent chance of continuing drugs.

D. SUMMARY OF THE CHAPTER

Sustained diastolic hypertensive diagnosis-treatment alternatives and their events have been structured in a decision tree. This decision tree has three strategies. The initial alternative for these three strategies are: conduct basic tests, administer drugs, and do nothing. Judgmental probabilities have been obtained for all uncertain events in the decision tree. An algorithm has been developed for reducing multiple consequences to a single level of effectiveness when the patient is the decision-maker and the government is the sole provider.

To obtain outcome preferences, analyst preferences must be assessed. The analyst must also assess patient preferences. The algorithm can then be used to develop single measures of effectiveness. When this is complete, the three problem strategies can be evaluated by "averaging out and folding back" as discussed in Chapter II.

V. PROBLEM SOLUTION RESULTS

Chapter IV formulated the sustained diastolic hypertension problem. This chapter analyzes this formulation using three patient decision-makers. These three decision-makers represent all three age groups and, as a result, analyze six of the 12 total health profiles.

The chapter is divided into two sections. Section A discusses decision analysis results. In particular, the results of each decision-maker analysis is presented, and selected sensitivity analyses are discussed. Section B describes limitations of the analysis conducted in Section A and suggests ways in which the solution can be made more complete.

A. DISCUSSION OF RESULTS

Three patients are used as decision-makers in the decision analysis of sustained diastolic hypertension: a 30 year old woman, a 45 year old man, and a 58 year old man. Table XVII gives the author assessments and the patient assessments for the gambles developed in Table X and Table XI. The author assessed each age category separately as these categories each have different health prognoses. The data in Table XVII are sufficient to calculate a single measure of effectiveness for each end point of the decision tree. These end point utilities and the judgmental probabilities can then be used to obtain a single measure of effectiveness for each of the three decision tree strategies. This is done using the "averaging out and folding back" technique described in Section B of Chapter II.

TABLE XVII. Author and Patient Assessments

Code*	30 yr. old woman	45 yr. old man	58 yr. old man
P_1	.7	.7	.7
P_2	.8	.8	.8
P_3	.5	.5	.5
P_4	.9	.9	.9
P_5	.6	.5	.4
P_6	.9	.95	.95
P_7	.7	.5	.7
AU1	.9	.95	.95
AU2	.8	.7	.9
AU3	.9	.95	.95

*See Table X and Table XI.

The single measure of effectiveness for the three treatment strategies for a 30 year old woman are given in Table XVIII. For a 60 percent chance that the patient continues drugs, the dominant strategy is to perform basic tests. This strategy is dominant for both blood pressure groups. The assumption that 60 percent of the patients continue drugs is highly questionable. As a result, the analysis is also conducted using a 90 percent chance that the patient continues drugs. The test strategy still reigns supreme, indicating women in this age group should be tested for surgically correctable causes of hypertension even if there is a high chance a patient will continue drugs.

It seems logical to infer from the above results that the test strategy is also optimal for men in this age group, since men are usually less inclined to continue drugs. Furthermore, men tolerate uncontrolled high blood pressure less well than women making it more serious when the male patient discontinues drugs.

TABLE XVIII. Analysis Results: 30 Year Old Female

Probability patient continues drug	Diastolic blood pressure mm Hg	Strategy Measures of Effectiveness (Utiles)		
		Test	Drugs	Nothing
.6	90 - 105	.93683	.93600	.92134
	105 - 120	.77011	.76126	.49623
.9	90 - 105	.94620	.94583	.92134
	105 - 120	.89851	.89607	.49623

The single measure of effectiveness for the three treatment strategies for the 45 year old man are given in Table XIX. For an 80 percent chance that the patient continues drugs and for blood pressures between 90 and 105 mm Hg, the patient prefers to be treated with drugs. In

other words, the inconvenience of taking drugs and the health consequences that result if drugs are not continued are more attractive than taking a chance on death during surgery. However, when the blood pressure is between 105 and 120 mm Hg, the patient prefers to be given basic tests. Again an 80 percent chance that the patient continues drugs is questionable. Therefore, the analysis is also performed for a 95 percent chance that a patient continues drugs. This analysis is done only on the higher blood pressure group as the optimal strategy in the lower blood pressure group is reinforced with this probability change. The analysis shows the patient still desires to be given basic tests.

It seems logical to infer that women in this age group in the 90 to 105 mm Hg blood pressure group have the same optimal strategy as men since women are more likely to continue drugs than men, and women have a better health prognosis if they discontinue drugs. The optimal strategy for women in the higher age group cannot be inferred from male results as the drug strategy is more attractive to women than men.

TABLE XIX. Analysis Results: 45 Year Old Male

Probability patient continues drug	Diastolic blood pressure mm Hg	Strategy Measures of Effectiveness (Utiles)		
		Test	Drugs	Nothing
.8	90 - 105	.97035	.97057	.96180
	105 - 120	.87383	.87088	.49917
.95	105 - 120	.94170	.94125	.49917

The measures of effectiveness for the three treatment strategies for the 58 year old man are given in Table XX. For the higher blood

pressure group with a 95 percent chance that drugs are continued, the optimal strategy is to conduct basic tests. For the lower blood pressure group with a 95 percent chance that drugs are continued, the optimal strategy is drug treatment. If the chance that a patient continues drugs is lowered to 80 percent, the lower blood pressure group still prefers to be treated with drugs.

The chance of death during surgery is assumed to be two percent in all age groups. However, the definition of "a low surgical risk" is less well-defined in the older age group. As a result, analyses are also conducted in the older age group using a four percent chance of death during surgery. Applying the increased death probability to the higher blood pressure group with a 95 percent chance drugs are continued resulted in a change in optimal strategy from basic tests to drug treatment. Again applying the increased death probability to the higher blood pressure group but now decreasing the chance drugs are continued to 80 percent resulted in a change in optimal strategy from drug treatment to basic test. This implies the older age group is sensitive to death probability.

The original assumption of low surgical risk and a 95 percent chance that drugs are continued resulted in the optimal strategy of drug treatment for the lower blood pressure group and in the optimal strategy of basic tests for the higher blood pressure group. As in the case of the 45 year old man, the optimal strategy of drug treatment can be assumed to hold for women; the optimal strategy of basic test cannot be assumed to hold for women.

TABLE XX. Analysis Results: 58 Year Old Man

Probability patient continues drug	Probability patient dies during surgery	Diastolic blood pressure mm Hg	Strategy Measures of Effectiveness (Utiles)		
			Test	Drug	Nothing
.95	.02	90 - 105	.98407	.98454	.97912
		105 - 120	.96586	.96559	.7
	.04	105 - 120	.96486	.96557	.7
.8	.02	90 - 105	.98313	.98358	.97912
	.04	105 - 120	.92506	.92358	.7

The decision analysis results for the three preceding cases are summarized in Table XXI. These results seemed intuitively plausible to the author. The result that a patient under 35 years of age always desires basic tests is logical since younger patients: incur a more severe health prognosis if drugs are discontinued, have a higher chance of a surgical cure, and are less prone to continue drug treatment. The result that a 45 year old man in the lower blood pressure group desires drug treatment is reasonable as this category of sustained diastolic hypertension has the lowest chance of being surgically correctable. The outcome of a 58 year old man in the lower blood pressure group desiring drug treatment is only natural as his condition is almost normotensive and would not justify the risk of surgery. Finally, the result of 45 and 58 year old men choosing basic tests if their blood pressure is between 105 - 120 mm Hg is logical as severe health complications result if this disease is not controlled. These results give credence to the way in which the sustained diastolic hypertension problem is formulated and to the decision analysis technique.

TABLE XXI. Analysis Results: Three Patients

Age (Years)	< 35		35-50		> 50	
M = Male F = Female	M	F	M	F	M	F
90 - 105 mm Hg	BT(I)	BT(TR)	DT(TR)	DT(I)	DT(TR)	DT(I)
105 - 120 mm Hg	BT(I)	BT(TR)	BT(TR)	(RU)	BT(TR)	(RU)

legend: 1. strategies: basic tests = BT
drug treatment = DT
nothing = N

2. result source:
test result = (TR)
inferred result = (I)
result unknown = (RU)

B. RESULT LIMITATIONS

The results given in Section A are not a complete analysis of the problem. Missing are a larger sample size of patient decision-makers, the government as a decision-maker, the doctor as a decision-maker, and more thorough sensitivity analyses. Patient assessments should be done on men and women for all 12 health profiles, vice the six profiles directly assessed in this work. Further, redundancy checks should be conducted by assessing several patients in each age group.

The government as a decision-maker appears highly appropriate in this case since the government is financing all medical services.

Recall Equation (5) where

$$u_c(\underline{x}_c) = K_g u_g(x_g)$$

and K_g represents the decision-maker's concern for government medical costs. Clearly, K_g is not zero when the government is the decision-maker. Inspection of Table VIII shows that the cost components of the result vector are less significant than the health components. Therefore, it is possible that decision analysis results, using the government as a decision-maker, are the same as the results given in Table XXI. However, for the analysis to be complete, the government must be included as a decision-maker.

The doctor as a decision-maker should also be included in the analysis. The reader is cautioned to note, however, that the doctor as a decision-maker when practicing medicine, and the doctor as a decision-maker when being assessed in a decision analysis are not the same. In the later case, the doctor is only giving his feeling about patient health factors and government cost factors. Assume that the doctor's concern for government medical costs is the same as that of the patient's concern ($K_g = 0$). Further assume that the doctor feels the same about patient health consequences as does the patient. These assumptions are not unreasonable. Then the decision analysis results, using the doctor as a decision-maker, are the same as results given in Table XXI.

A critical part of a decision analysis is sensitivity analysis, where one problem parameter is changed while all other problem parameters remain fixed. Sensitivity analyses have been done for the

following problem parameters: the probability drugs are continued, and the probability of death during surgery (for one age group). However, a complete sensitivity analysis requires that all problem parameters be tested. Judgmental probabilities should be varied to determine their effect on the problem. Analyst assessments should be varied to determine their effect on the problem. These analyses would isolate the critical problem parameters. Critical problem parameters can then be scrutinized for credibility.

C. SUMMARY OF THE CHAPTER

The results of the decision analysis for the three patient decision-makers are intuitive. These results give credence to the hypertensive problem formulation and to the decision analysis technique.

For the decision analysis of specific diagnostic categories in the public sector where the government is the sole provider, the patient is viewed as a viable decision-maker. However, a more complete analysis of the problem formulation requires the government to be used as a decision-maker and the doctor to be used as a decision-maker. In addition, a complete sensitivity analysis should be performed.

VI. SUMMARY AND CONCLUSION

A decision analysis was conducted on the specific diagnostic category of hypertension. Specifically, sustained diastolic hypertension was analyzed as this type of hypertension was common and standard diagnosis-treatment procedures were lacking.

The problem of analyzing sustained diastolic hypertension was complicated by hypertensive patients having unique health profiles. The continuum of unique health profiles was broken down into 48 discrete health profiles. Twelve of these profiles were selected for analysis. These profiles were low surgical risk male and female patients with:

1. no secondary symptoms,
2. diastolic blood pressure either between 90 and 105 mm Hg or 105 and 120 mm Hg, and
3. one of three age groups: below 35, between 35 to 50, and over 50 years of age.

These discrete profiles represented medical cases where standard diagnosis-treatment procedures were needed.

There were three treatment options for each of the 12 hypertensive profiles: treat hypertension with drugs, investigate for surgically correctable causes of hypertension, or do nothing. The decision analysis of these three options was done in two parts - formulate the problem and solve the problem. The formulation phase of the decision analysis was emphasized in this work as it was felt ensuing solutions to the formulated problem would be routine.

The problem formulation phase of the decision analysis consisted of structuring the problem, obtaining judgmental probabilities, and

establishing preferences of outcomes. The problem was structured by chronologically arranging diagnosis-treatment alternatives and their possible events. This resulted in three possible treatment strategies, one for each treatment option. These strategies were to conduct laboratory tests, administer drugs, or do nothing. Judgmental probabilities were assigned to the uncertain events identified in the problem structure. The sources for these probabilities were selected medical physicians and medical statistics. The final step in the problem formulation consisted of applying multidimensional utility theory to the possible outcomes in order to reduce multiple outcomes to a single measure of effectiveness.

In the solution phase of the decision analysis, decision-makers made trade-offs among possible outcomes. These trade-offs were then put into the problem formulation to obtain a single measure of effectiveness for each of the three treatment strategies.

Three parties of decision-makers had interest in decision outcomes. These decision-makers were the patient, the doctor, and the outside provider (i.e., the government). To limit the solution phase of the decision analysis, this paper solved the problem using only the patient as a decision-maker. The patient was viewed as a viable party to make trade-offs among possible outcomes.

The decision analysis was conducted using three patients that represented six of the 12 total health profiles. These analyses were conducted in the environment of a military installation where the government was the sole provider. Decision analysis results from these three patients indicated whether a patient desired to be tested, put on drugs, or not treated. Results obtained were intuitive appealing,

giving credence to the problem formulation and solution technique.

Results were compromised by three factors:

1. limited sample size of patient decision-makers,
2. use of patients only as decision-makers, and
3. limited sensitivity analysis.

A comprehensive analysis of the hypertension problem as it has been formulated requires additional efforts in the above areas.

To conclude, decision analysis was shown to be an effective means of obtaining substantive diagnosis-treatment procedures in specific diagnostic categories. Uncertain events in the medical decision process were exposed. As a result, professional expertise could be brought to bear on the probable occurrence of these events. Possible outcomes of various diagnosis-treatment procedures were identified. Rational trade-offs could then be made among these outcomes. This recognition of critical problem elements and integration of professional expertise created viable solution results.

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